NATIONAL BUREAU OF STANDARDS REPORT

9572

CAPACITY TESTS OF FOUR REMOTE FORCED CIRCULATION REFRIGERATION EVAPORATORS

Manufactured by

Thermo King Corporation
Minneapolis, Minnesota

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

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CAPACITY TESTS OF FOUR REMOTE FORCED CIRCULATION REFRIGERATION EVAPORATORS

Manufactured by

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CAPACITY TESTS OF FOUR REMOTE FORCED CIRCULATION

REFRIGERATION EVAPORATORS

Manufactured by

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1.0 Introduction

This report presents results of capacity tests of four remote, forced circulation, refrigeration evaporators, of the same class and of four different sizes listed in QM R&E IP/DES S-9-8, "Interim Purchase Description, Refrigeration Evaporators, Forced Circulation, for Use with Dichlorodifluoromethane (F-12)", dated January 31, 1958. All four were manufactured by the Thermo King Corporation, Minneapolis, Minnesota.

The four evaporators were:

1) Class A Size 1
Copper Tubes, Aluminum Fins
NBS Specimen No. 180-58

2) Class A Size 2
Copper Tubes, Aluminum Fins
NBS Specimen No. 181-58

3) Class A Size 3
Copper Tubes, Aluminum Fins
NBS Specimen No. 182-58

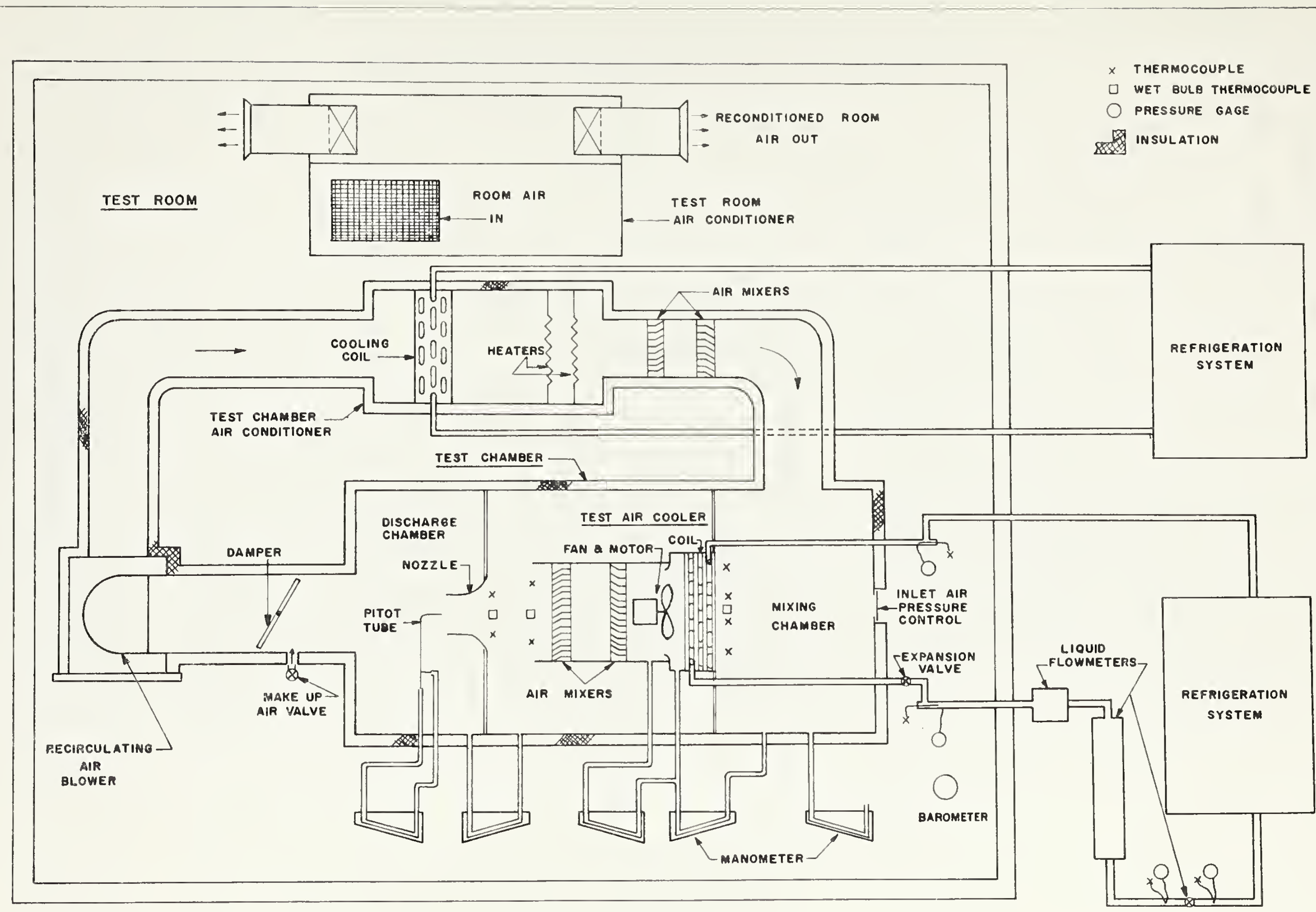
4) Class A Size 4
Copper Tubes, Aluminum Fins
NBS Specimen No. 183-58

All specimens were procured under contract No. DA-19-129-QM-1236.

1.1 Background

This report is one of three presenting test data on the performance of forced circulation refrigeration evaporators. Each of the other two reports in this series presents test data on the performance of four evaporators of the same military sizes as this report, but constructed by different manufacturers.

The test apparatus used for this series of tests was constructed by modifying an apparatus previously developed at NBS for U.S. Army Natick Laboratories for the testing of remote air-cooled refrigeration condensers in accordance with ASRE (American Society of Refrigerating Engineers) Standard PS-2.4. The apparatus was modified and developed in two stages to conform to ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) Standard 25-56, "Method of Rating Air Coolers for Refrigeration," between March and October 1962 and between October and December 1964. Tests were run on the twelve coils, four of which are reported here, between December 1964 and August 1966. To accommodate other investigations of higher priority to QM R&E , this project was deferred for approximately one year between the two stages. Subsequent to implementation of the project, a revision of ASHRAE 25-56 has been proposed. The primary change between the original standard and its revision is the elimination of capacity determination using the psychrometric (air side) measurement and substitution of the measurement of the refrigerant flow with two independent flow meters. The apparatus as used is shown schematically in figure 1. Provision was retained for measurement of capacity by air side measurement; however, it was found necessary to provide air mixers both at the inlet and outlet of the test coil for stable, repeatable air temperature measurements.



PSYCHROMETRIC CALORIMETER FOR AIR COOLER TESTS

Figure 1

ASHRAE Standard 25 was prepared for the testing of entire air cooler units including fans, expansion valves, heat exchangers, casings etc. For these tests, ASHRAE 25-56 was used as a guide to determine the conformance of the test coils with the requirements of IP/DES S-9-8 which deals primarily with the evaporators. A principal objective of the investigation was to determine the interchangeability (from the standpoint of capacity) of the various manufacturers' evaporators.

The expansion valve supplied with each coil was removed before testing and replaced with a specially selected valve which would permit comparison of the performance of the evaporators without consideration of the performance of different thermostatic expansion valves.

Although IP/DES S-9-8 requires draw-through fans all four evaporators were supplied with blow-through fans and fan orifices arranged for blow-through operation. New fans of the draw-through type identical to the original fans except for air flow direction were procured from the Torrington Company, manufacturer of the original blades. The fan orifices were reversed and the fan motors and new fans were reinstalled on the same side of the coil as supplied. This had the effect of reversing the direction of air flow through the coil from the manufacturer's original setup. Reversing the coil in the end tube sheets and fan housing for these units would have required major rebuilding of the evaporator assembly. The evaporators were equipped with integral heat exchangers and, using the special expansion valve, the tests were conducted with refrigerant leaving the evaporator at or near saturation (5.1 deg F superheat or less for all tests) to minimize the effect of reversing the air flow direction through the coil.

QM R&E Interim Purchase Description, "Refrigeration Evaporators, Forced Circulation, for Use with Dichlorodifluoromethane (F-12)" dated January 31, 1958,

set forth the following capacity requirements. At a refrigerant saturation temperature of -10 °F, corresponding to the pressure at the suction outlet of the evaporator, and an inlet air dry bulb temperature of 0 °F, the minimum capacities for the four sizes of evaporators are:

Size I	4500 Btu/hr
Size II	6500 Btu/hr
Size III	10,000 Btu/hr
Size IV	13,000 Btu/hr

Capacities have been determined at these conditions and also at the following conditions as suggested in ASHRAE 25-56:

Dry Bulb Temp. °F	Wet Bulb Temp. °F	Nominal RH, %	Refrigerant Temp. °F
50	45	70	35
30	-	-	18
-10	-	-	-22

ASHRAE 25-56 suggests a fourth rating condition at -30 °F dry bulb temperature and -40 °F refrigerant temperature. The refrigeration capacity of the test apparatus was not adequate to pull the test chamber temperature down to the level this test requires.

2.0 Test Apparatus and Procedure

Tests were run in general conformance with requirements of ASHRAE Standard 25-56, "Method of Testing for Rating Air Coolers for Refrigeration."

Because ASHRAE Standard 25-56 is intended primarily for testing of entire air coolers whereas these tests were primarily concerned with comparative evaporator performance, and for other reasons, certain deviations were made from the standard in conducting tests. A few points of non-conformance are discussed below.

1) The requirement in Section 4.1.2 of ±0.1 deg F accuracy of absolute temperature measurements is unrealistic. For normal laboratory quality measuring systems ±0.2 deg F is more realistic, and test results reported were based on measurements approaching this degree of accuracy.

2) The thermostatic expansion valves which were supplied with the coils were replaced with specially selected thermostatic expansion valves with a changeable maximum coil pressure setting. Two of these valves, of 1 and 1 1/2 ton nominal sizes, were used to cover the range of coil sizes tested. The same valve was used for all coils of appropriate size.

ASHRAE Standard 25-56 describes a test procedure for air cooler units incorporating fans and expansion valves as well as evaporators. It was desired in the series of tests to compare evaporators (principally) with the variability of valve performance removed from the test. It was also found that some normal expansion valves were not sufficiently stable in performance to enable easy maintenance of steady-state test conditions.

3) In the ASHRAE Standard 25-56 test method, the air flow rate over the coil is established by the fan and motor as supplied with the assembled air cooler. Military Interim Purchase Description S-9-8 specifies minimum air flow rates for

the different size coils for the 0 ^{o}F entering air -10 ^{o}F refrigerant test as follows:

Mil. Std. Evap. Size	Minimum Air Quantity, CFM
I	750
II	1100
III	1500
IV	2200

As described earlier the units were fitted and tested with draw-through fans identical otherwise to the blow-through fan supplied and selected by the evaporator manufacturer to provide the required minimum air flow capacity. With the fan running, the minimum required air flow rate was obtained for each test by adjusting the dampers on the auxiliary blower in the psychrometric calorimeter to produce a suitable pressure downstream from the fan in the test unit.

4) ASHRAE Standard 25-56 specifies a superheat of 5 to 8 deg F in the refrigerant leaving the air cooler under test. This is not a practical requirement for a unit with an integral liquid-suction heat exchanger when a thermal expansion valve is used for refrigerant flow control and the expansion valve bulb is mounted on the suction line ahead of the heat exchanger. Even though the actual refrigerant superheat is held quite low at the thermal expansion valve bulb the superheat in the refrigerant leaving the heat exchanger (and the air cooler assembly) is likely to be in excess of 8 deg F. All of the capacity tests covered in this report were made with the refrigerant leaving the evaporator (entering the heat exchanger) saturated or at a low superheat but with a positive superheat ranging from 2.0 to 19.4 deg F at the outlet of the heat exchanger. This was done to obtain highest cooling capacity for a coil equipped with an integral heat exchanger.

The two independent measuring systems are shown schematically in figure 1 and can be described briefly.

1) Air-side or Psychrometric. The test evaporator was mounted in an insulated, closed-loop, air duct apparatus with temperature and humidity controlled at the specified evaporator entering air conditions.

Figure 2 shows the Size I Thermo King evaporator and fan assembly during installation in the psychrometric calorimeter. The discharge test duct and air mixer can be seen in the foreground. The apparatus was enclosed in a test room with controlled ambient conditions. The air was drawn through the evaporator by its fan mounted directly on the unit and by a large auxiliary blower with an adjustable damper which was used to control the air flow rate and system pressure at the specified values. Evaporator heat absorption capacity was determined by measuring air quantity and enthalpy change and correcting for fan motor energy imput. Air quantity was measured with an ASME long radius nozzle.

2) Liquid refrigerant flowmeter. The subcooled condensed liquid refrigerant was metered by means of a totalizing (integrating) piston-type positive displacement flowmeter, and heat absorption capacities were determined from refrigerant mass flow and enthalpy change. A variable head meter was read and used as a flow check during steady-state periods. A cylindrical tank, built and instrumented by the NBS Fluid Meters Section, which showed the quantity of refrigerant contained by the position of a piston which formed one of its ends was installed in the system and used as a calibration device.

The required conditions of inlet air temperature were determined by a multiple grid arrangement of a calibrated thermocouples and a precision potentiometer. Inlet humidity (for the 50 ^{o}F test) was measured with calibrated thermocouple psychrometers. The absolute suction pressure, from which the required refrigerant temperature was determined, was measured with a calibrated, precision grade, aneroid absolute pressure gage. Other temperatures were read using calibrated thermocouples and an electronic potentiometer. Air pressures in the fan circuit were measured with calibrated slope gages referenced to a calibrated aneroid barometer.

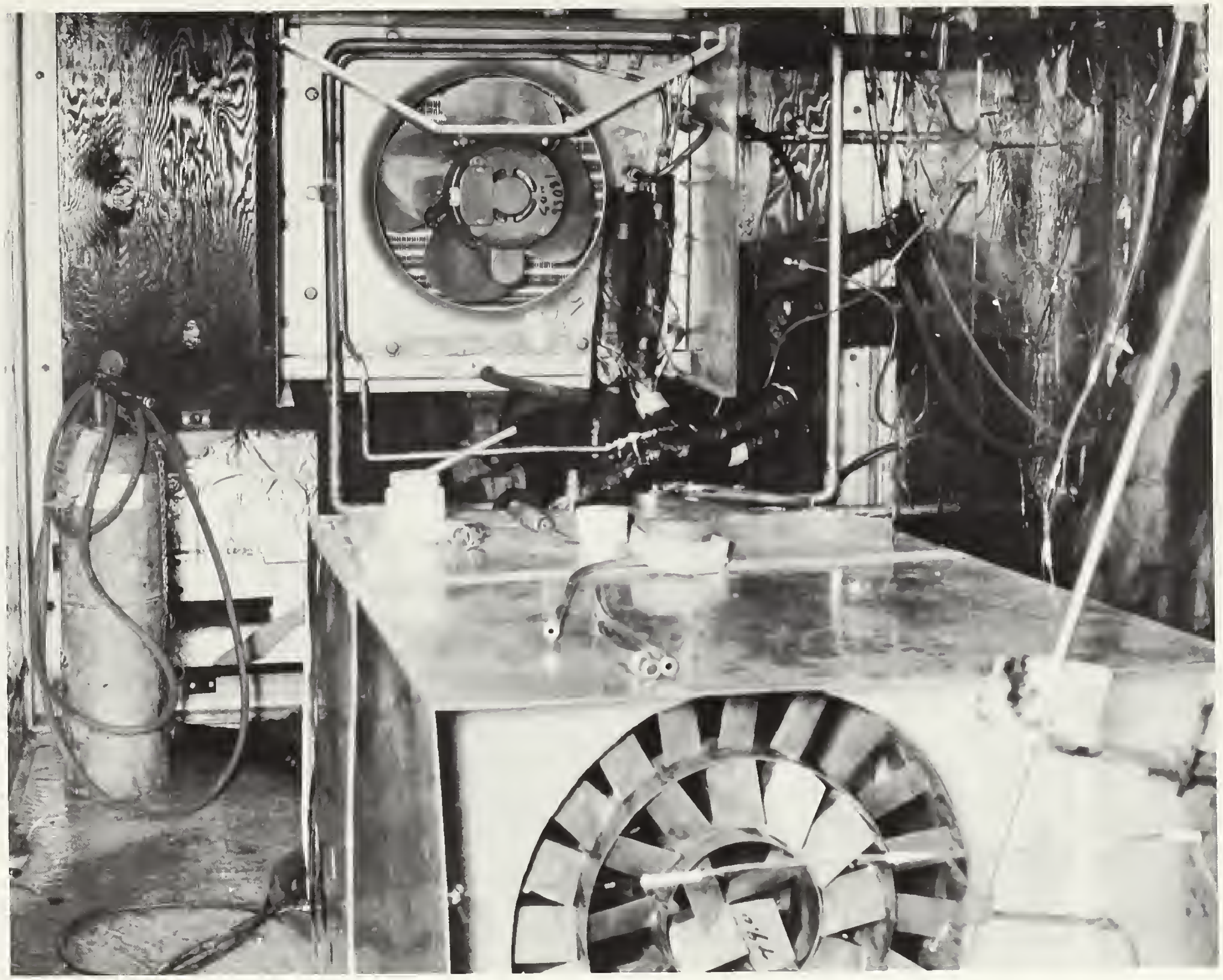


Figure 2. Test coil during installation in psychrometric calorimeter. Note discharge test duct and air mixer in foreground.

3.0 Test Specimens

3.1 Four Class A Thermo King forced circulation refrigeration evaporators were tested. As furnished, each was mounted in a metal casing with a blow-through fan, fan motor, and bellmouth fan orifice arranged for blow-through operation. For the tests an otherwise identical draw-through fan was used and the bellmouth fan orifice was reversed. All units were equipped with installed thermostatic expansion valves and all had integral heat exchangers formed by soldering the liquid and suction lines together for a length of several feet. Table 1 gives the related physical data for the four units.

The aluminum fin and copper tube assembly was similar for all units (except for numbers of tubes and rows) and is shown in figures 3 and 4. Figure 3 is a section of one coil and clearly shows the staggered arrangement of tubes in adjacent rows. The end tube sheet formed part of the housing. Figure 4 is a close-up view of the tube and fin collar configuration. The bonding of the tubes and fins was accomplished by mechanical expansion of the tubes and final expanded diameter of the tubes was approximately 0.52 in. In addition to providing bond surface the fin collars determined fin spacing.

The four Thermo King evaporator and fan assemblies were enclosed in an outer metal casing. Figure 5 shows the Size II unit, which was typical of the four units in respect to the housing. Figure 6 is a schematic drawing of the typical configuration of evaporator and housing.

TABLE 1. PHYSICAL CHARACTERISTICS

THERMO KING AIR COOLERS

QMR & E Size		I	II	III	IV
QMR & E Class		A	A	A	A
NBS Specimen No.		180-58	181-58	182-58	183-58
COIL TUBE CHARACTERISTICS					
MATERIAL		Copper	Copper	Copper	Copper
Number of Rows Deep		4	6	6	4
Number of Tubes High		16	16	18	32
Number of Circuits in Parallel		4	4	6	8
Number of Tubes per Circuit		16	24	18	16
Tube Diameter, O.D., in.		0.521	0.523	0.521	0.522
Tube Diameter, I.D., in.		.471	.476	.478	----
Tube Wall Thickness, in.		.025	.024	.021	----
Tube Return Bend Diameter, O.D., in.		1/2	1/2	1/2	1/2
Vapor Outlet Diameter, O.D., in.		3/4	7/8	1 1/8	1 1/8
Liquid Inlet Diameter, O.D., in.		1/2	1/2	5/8	5/8
Vertical Spacing of Tubes, in.	S	1 1/4 Tubes staggered horizontally	1 1/4 Tubes staggered horizontally	1 1/4 Tubes staggered horizontally	1 1/4 Tubes staggered horizontally
Horizontal Spacing of Rows, in.		1	1	1	1
Integral Heat Exchanger		Yes Liquid & suction lines soldered	Yes Liquid & suction lines soldered	Yes Liquid & suction lines soldered	Yes Liquid & suction lines soldered
COIL FIN CHARACTERISTICS					
MATERIAL		Aluminum	Aluminum	Aluminum	Aluminum
Type of Fin		Plate Flat	Plate Flat	Plate Flat	Plate Flat
Fin Spacing, Fins per inch		6 142 Fins	6 139 Fins	6 188 Fins	6 192 Fins
Fin Thickness, in.		0.015	0.015	0.015	0.015
COIL DIMENSIONS					
Finned Height, in.	K	20	20	22 1/2	40 1/8
Finned Width, in.	F	23 3/8	22 1/2	30 1/2	31
Finned Depth, in.	V	4	6	6	4
Coil Height, in.	H	19 3/8	19 1/2	21 7/8	39 1/2
Coil Width, in.	W	25 1/2	24 1/2	31 7/8	33 1/2
Coil Depth, in.	D	3	5	5	3
Face Area, Sq. Ft.		3.04 (18 3/4" x 23 3/8")	2.93 (22 1/2" x 18 3/4")	4.73 (30 1/2" x 22 5/16")	8.66 (31 1/16" x 40 1/8")
SURFACE AREAS					
Primary Area, Sq. Ft.		1.36	1.97	3.00	3.61
Secondary Area, Sq. Ft.		10.63	15.61	22.67	28.87
Total Area, Sq. Ft.		11.99	17.58	25.67	32.48
OVERALL DIMENSIONS					
Width, in.	A	26 1/2	26 5/8	34 5/8	34 1/2
Width, Shroud, in.	B	23 3/8	22 5/8	30 1/2 Inside	31 3/16
Height, in.	C	20 1/16	20	25	43 3/4
Depth, in.	E	9	12	13	17 1/4
Fan Orifice Diameter, in.	X	14 1/4	16 5/16	18 3/16	22 1/2
Fan Orifice Radius, in.	R	1 1/4	1 3/16	1 1/8	2

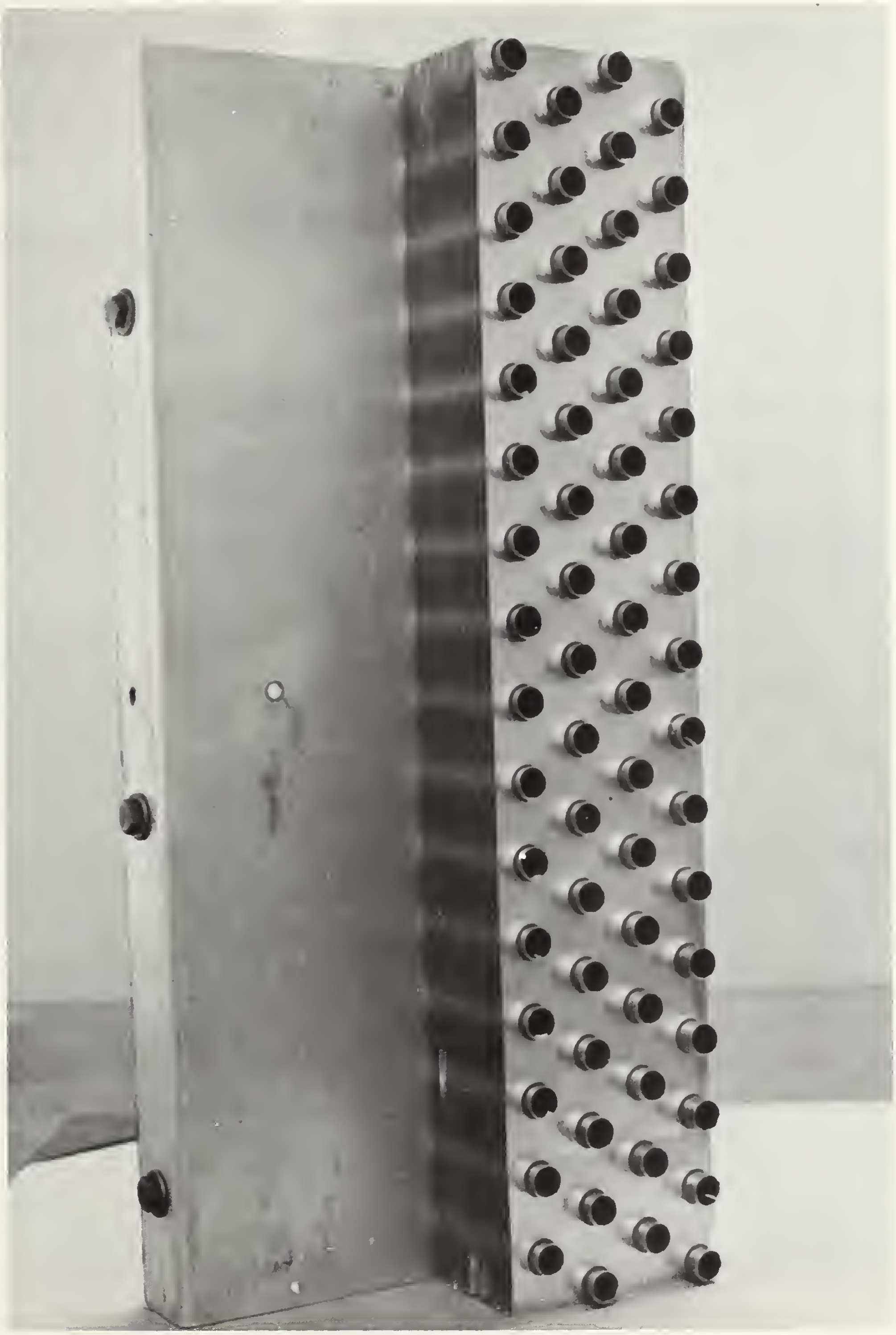
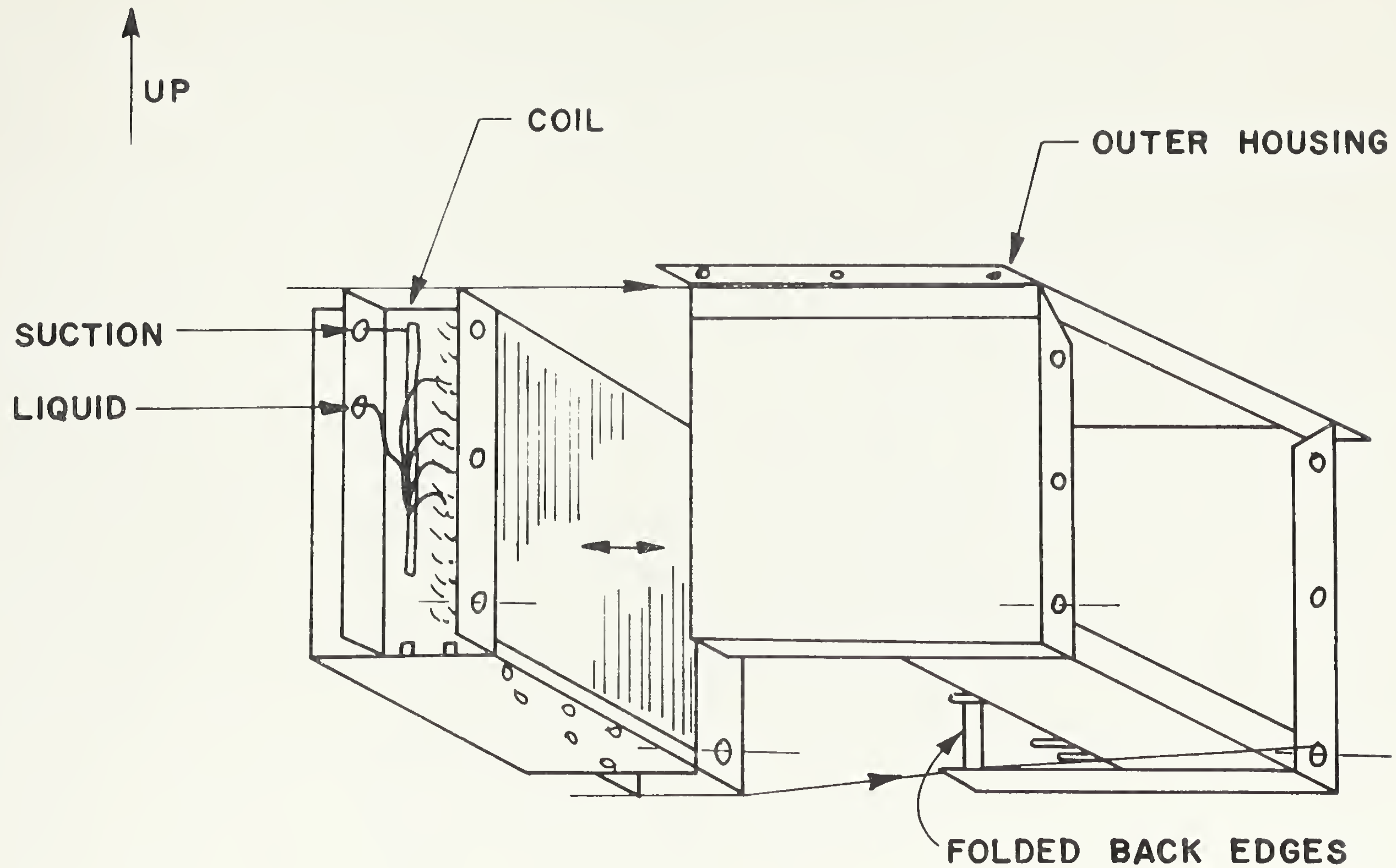


Figure 3. Section of typical Thermo-King coil showing fin and tube assembly.

Figure 4. Typical Thermo-King fin collar and tube assembly.

Figure 5. Typical Thermo-King housing and coil assembly.

THERMO KING AIR COOLERS



TYPICAL ASSEMBLY OF EVAPORATOR & HOUSING

Figure 6

3.1.1 NBS Specimen No. 180-58 was a Size I Class A evaporator with copper tubes and aluminum fins. Figure 7 shows the fully assembled unit as supplied. The integral heat exchanger formed by soldering the liquid and suction lines together can be seen to the left and above the fan orifice. Note the blow-through arrangement of fan and fan orifice. Figures 8 and 9, respectively, show the coil details of the units as supplied, but with the housing, fan, fan motor, and drain pan removed. Figure 8 is a view of the air inlet side (as tested) and left end of the four-row, staggered-tube coil. The exterior housing, drain pan, fan and fan motor have been removed. Figure 9 is a view of the right end and air discharge side (as tested--note that the fan orifice has not yet been reversed for test) of the coil showing the expansion valve, distributor tube and suction header arrangement. Distributor tubes are connected to the 3rd, 7th, 11th and 15th tubes from the bottom in the second row from the left.

The defrost header is the right hand vertical tube with connections to the bottom 5th, 9th and 13th return bends. The hot gas for defrost enters the unit through a coil in the bottom of the drain pan and then into the defrost header as shown. Figure 10 is a schematic illustration of the arrangement of the housing and drain pan defrost coil for the Size I unit, and Figure 11 shows schematically the evaporator and fan orifice details for this unit. Related physical data are given in table 1.

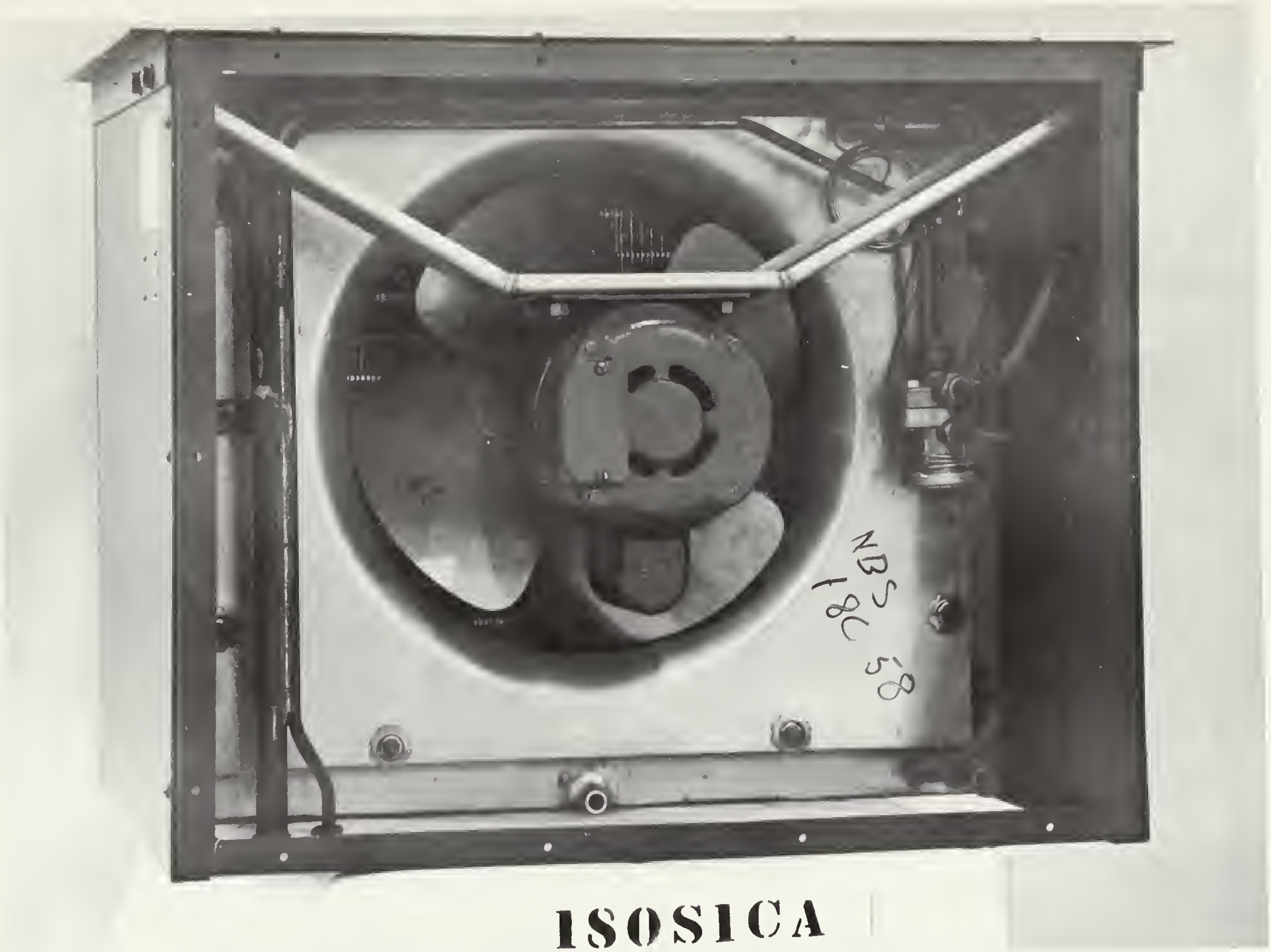


Figure 7. Size I evaporator (NBS No. 180-58), housing, and fan assembly as supplied.

Figure 8. Air inlet side (as tested) and left end of Size I evaporator (NBS No. 180-58) with housing removed.

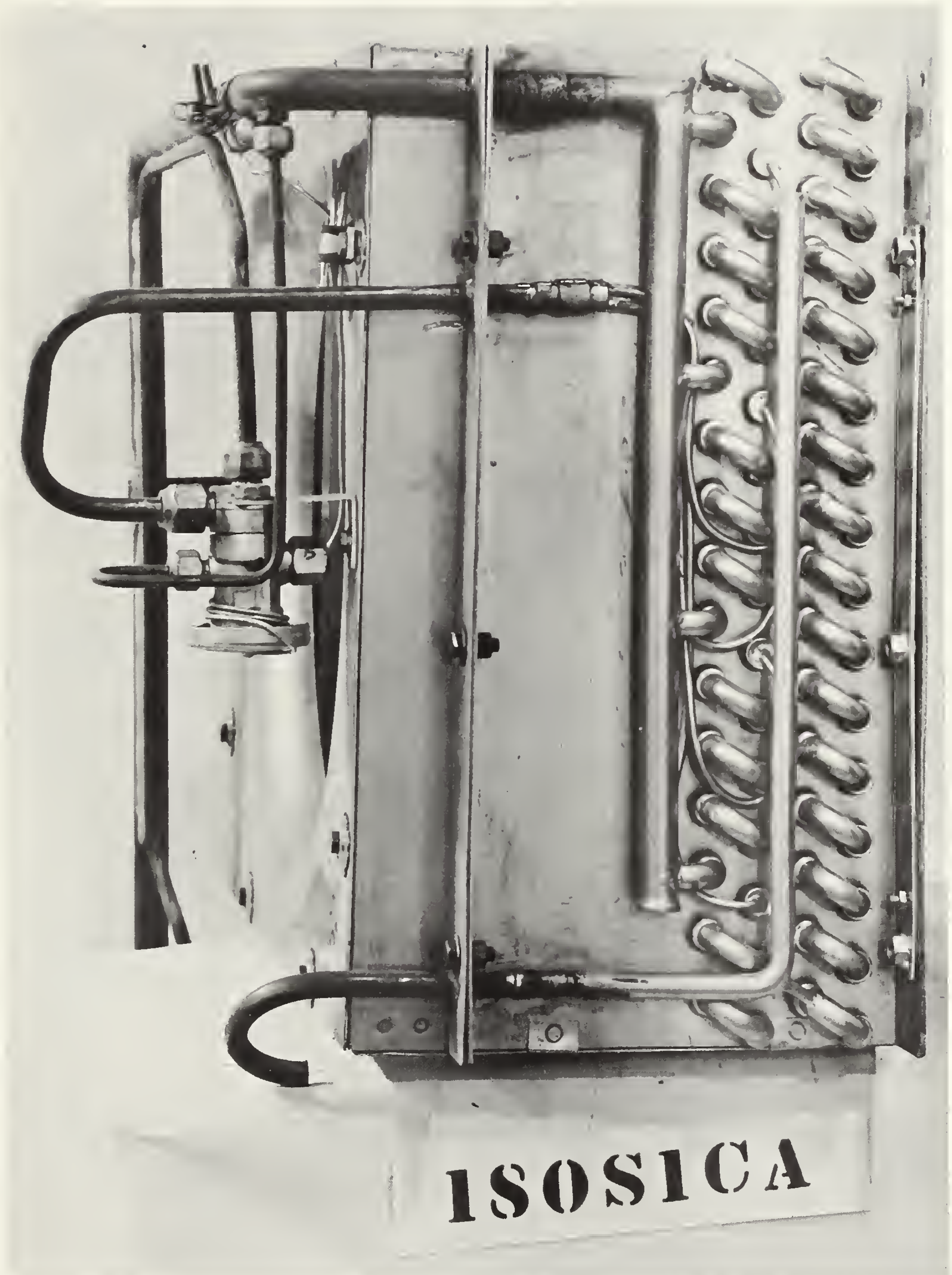


Figure 9. Air discharge side (as tested) and right end of Size I evaporator (NBS No. 180-58) with housing removed. Fan orifice in position as supplied.

SPECIMEN NO. 180-58 HOUSING

THERMO KING SIZE I

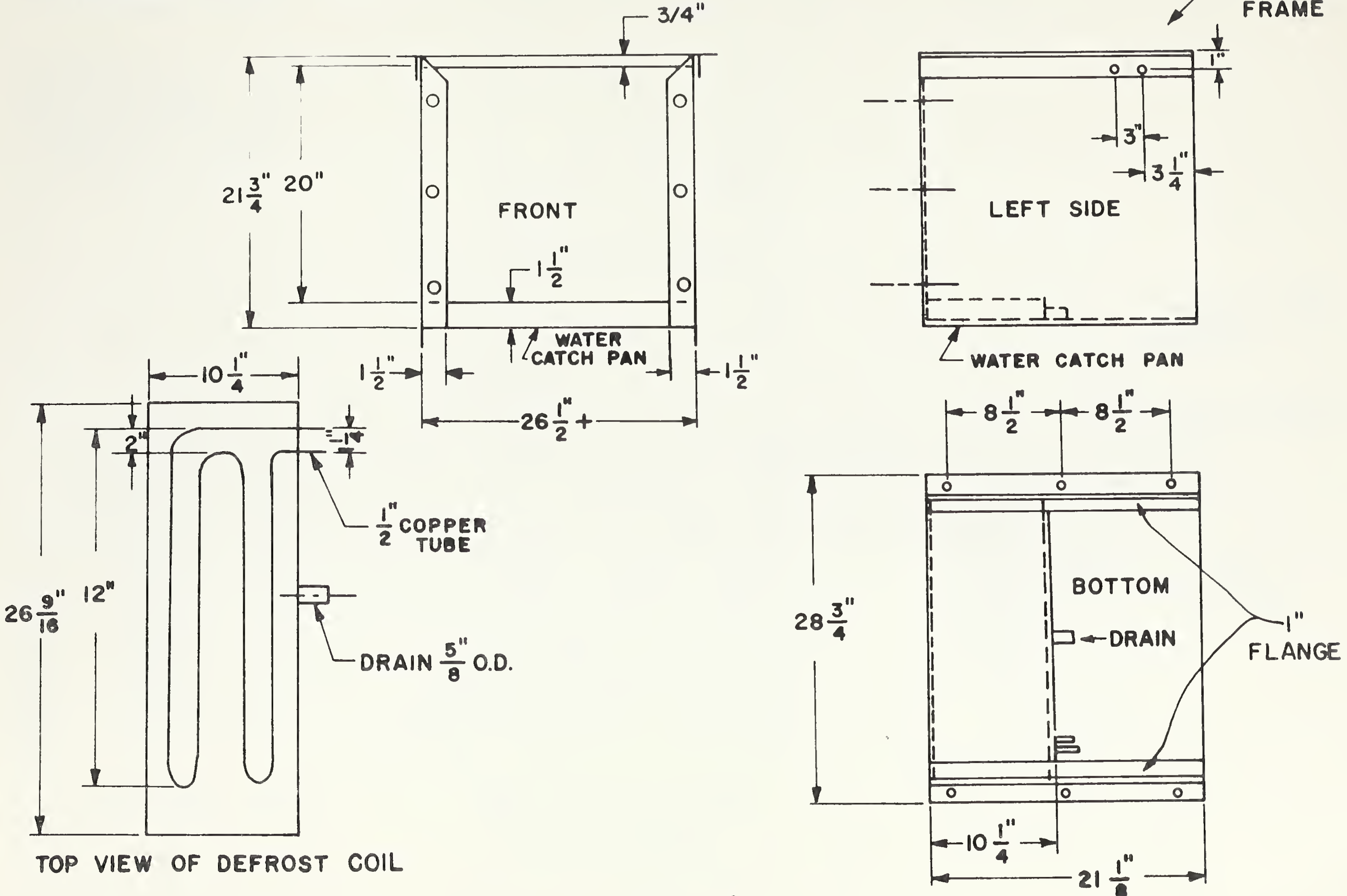


Figure 10

THERMO KING

EVAPORATOR SPECIMEN
NBS NO. 180-58

SIZE I CLASS A

NOTE: THESE VIEWS DO NOT SHOW THE COMPLETE HOUSING AS IT WAS TESTED.

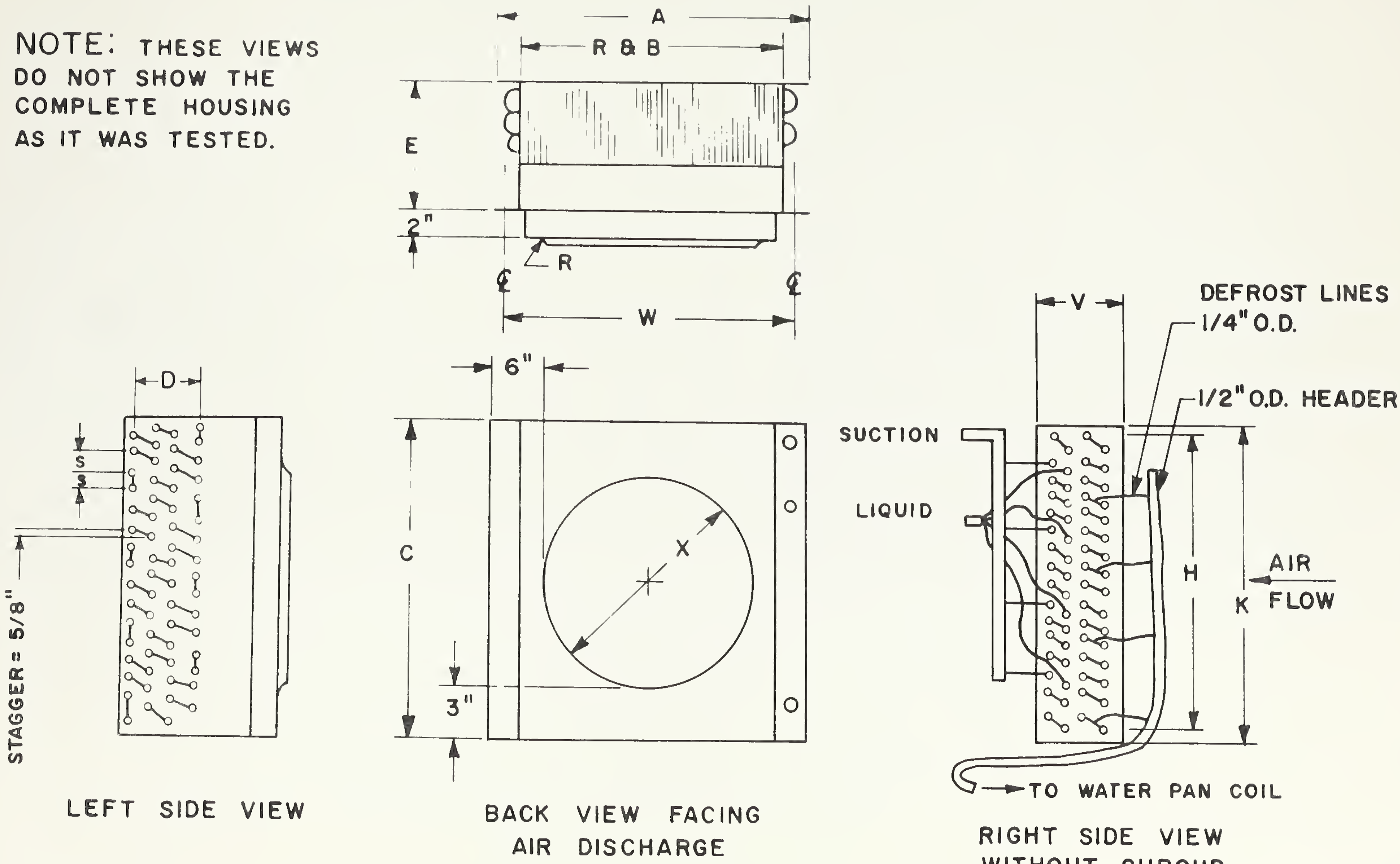


Figure 11

3.1.2 NBS Specimen No. 181-58 was a Size II Class A evaporator with copper tubes and aluminum fins. Figure 12 is a view of the left end and air discharge side of this unit with the orifice plate reversed for test. The exterior housing, drain pan, expansion valve, fan and fan motor have been removed. The small tube at mid-height of the near end of the coil housing is one of two taps in the housing used in measuring the air pressure drops across the coil and fan. Figure 13 shows the right end of the six-row coil with the distributor, suction header and defrost header. The thermocouples shown soldered to various return bends were used to determine refrigerant temperatures in the several circuits. Figure 14 shows schematically the exterior housing and Figure 15 is a schematic drawing of the evaporator assembly. Table 1 contains the related physical data for this unit.

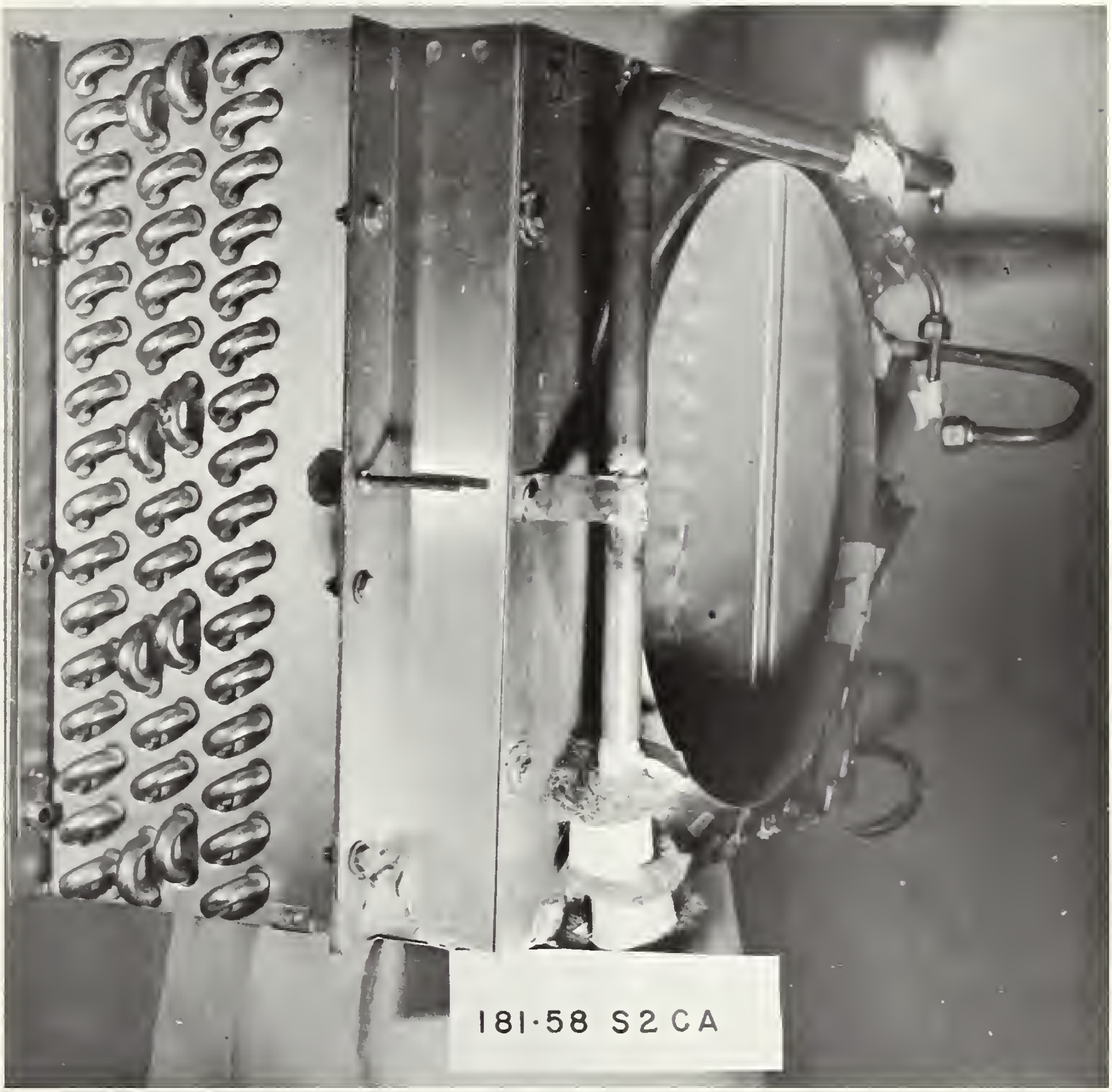


Figure 12. Left end and air discharge side of the Size II evaporator (NBS No. 181-58) with orifice plate reversed for test.

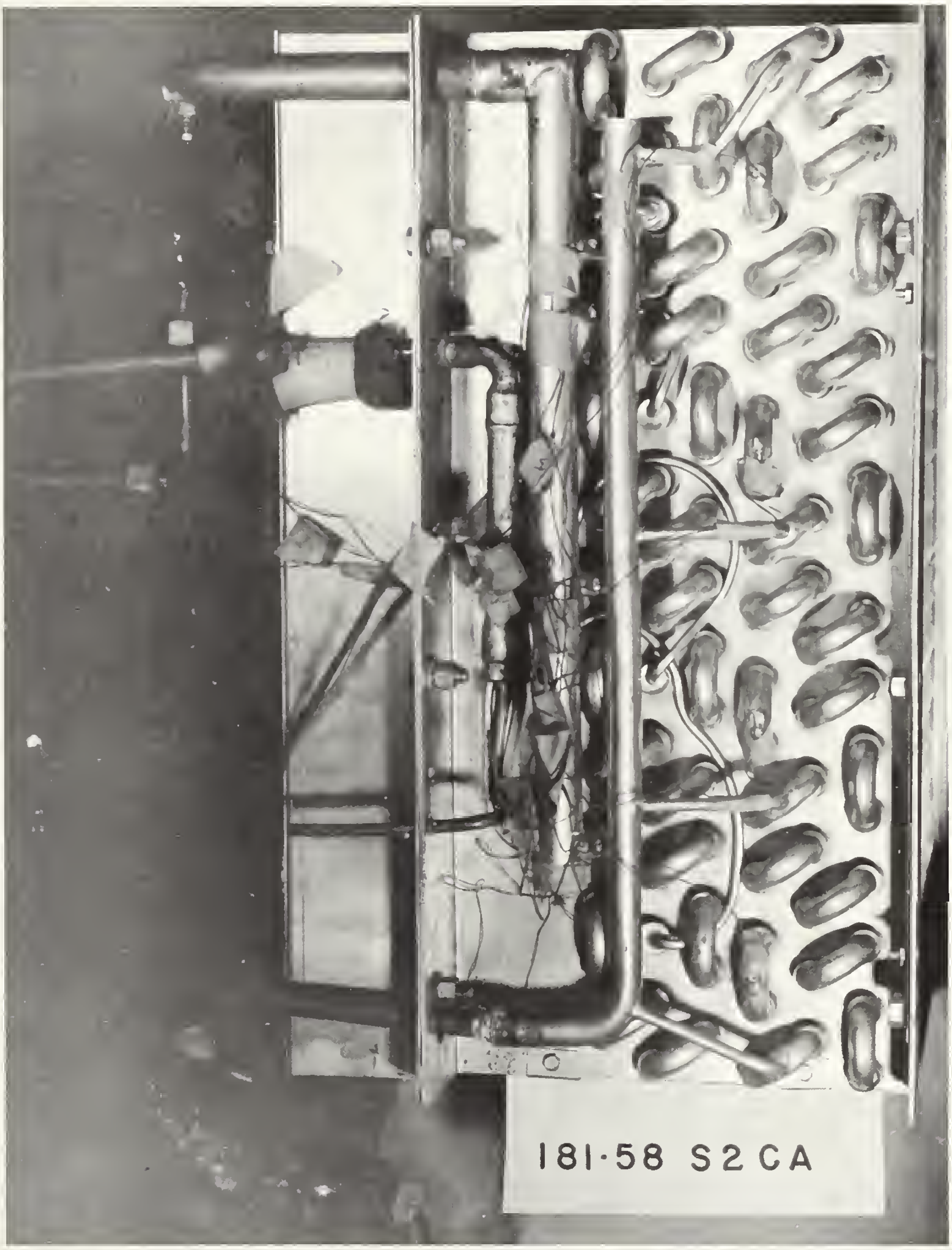


Figure 13. Right end of the Size II evaporator (NBS No. 181-58).

SPECIMEN NO. 181-58 HOUSING
THERMO KING. SIZE II

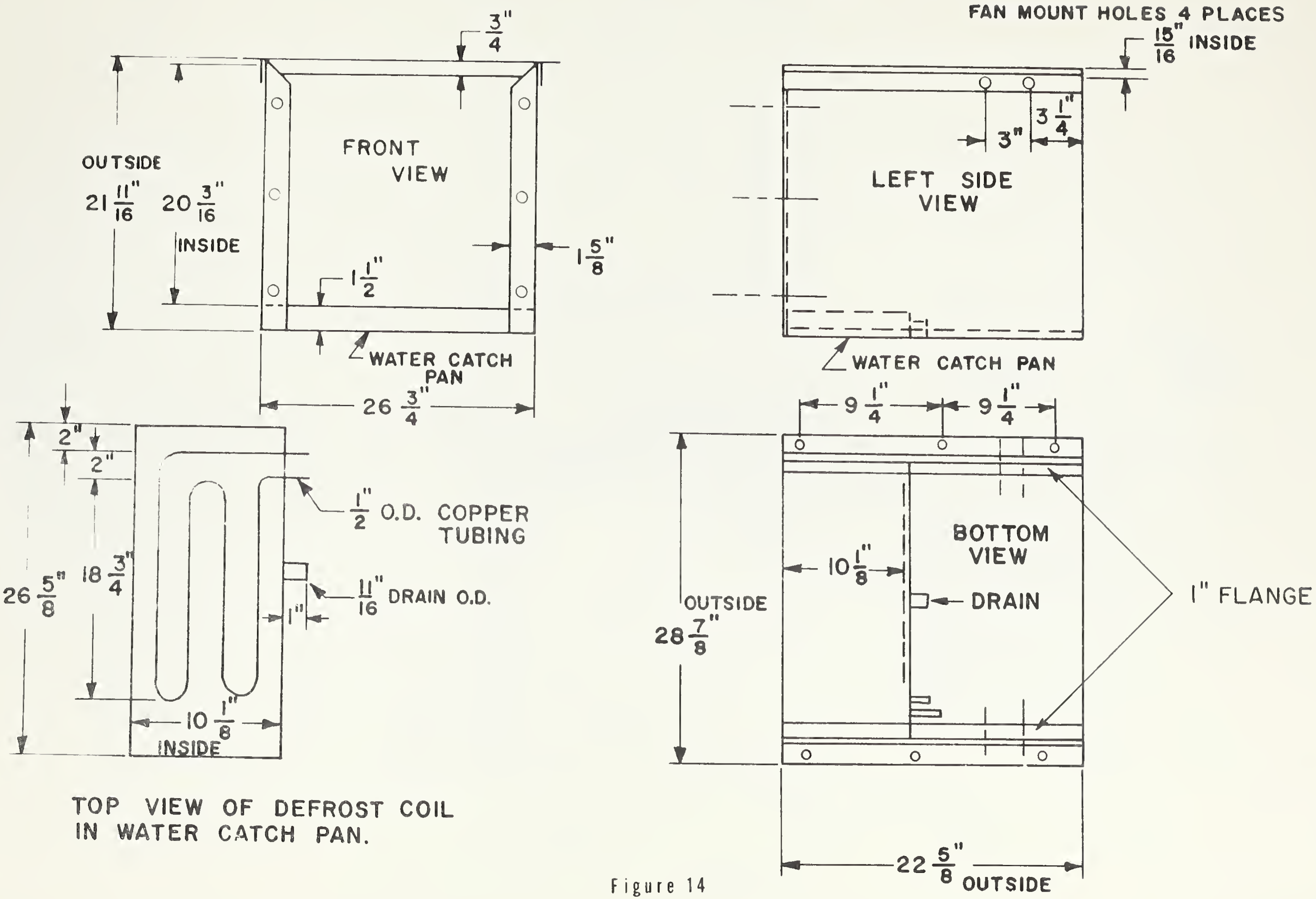


Figure 14

EVAPORATOR SPECIMEN

THERMO KING NBS NO. 181-58 SIZE II CLASS A

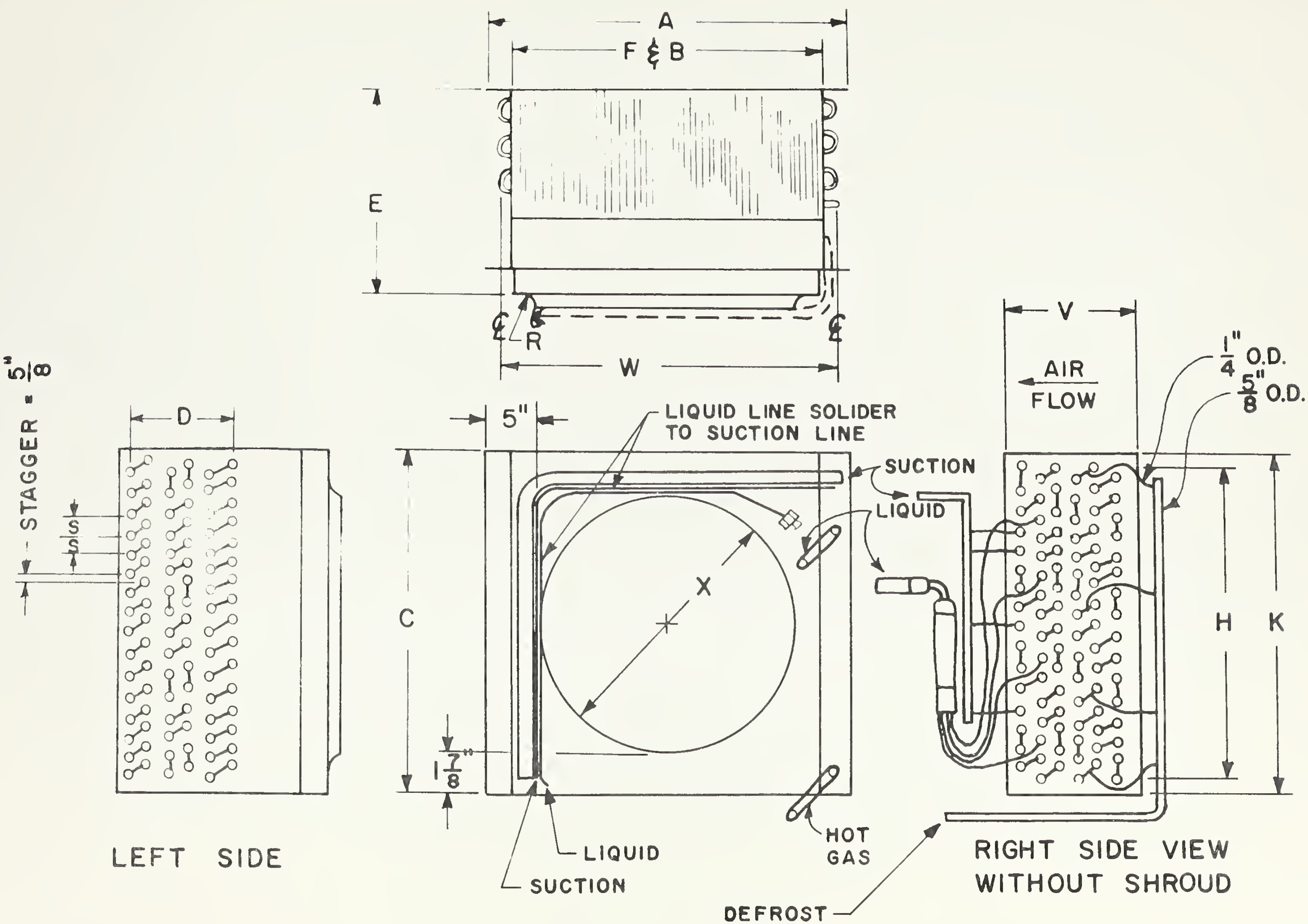


Figure 15

3.1.3 NBS Specimen No. 182-58 was a Size III Class A evaporator with copper tubes and aluminum fins. Figure 16 is a view of the fully-assembled unit as supplied. Note the blow-through arrangement of the fan and fan orifice which were changed and reversed, respectively, to draw-through operation for the tests. As typical for all four Thermo King units the fan motor position and rotation were not changed. The exterior housing was removed for the tests of the Size III and IV units. Figures 17 and 18, respectively, show the left and right ends of the evaporator as mounted for test. Both show the fan orifice as reversed for test. The angle strips on the orifice plate were installed to mount the discharge air mixer duct. New fan motor mounts to accommodate the mixer duct were installed for the Size III and IV units. For the Size III and IV units, the drain pan was integral to the bottom of the coil and remained in position even though the exterior housing was removed for test. As for all units, the defrost tube was sealed at its inlet during all tests. The defrost header connections to the mid-points of the six coil circuits can be seen on the right hand side of the end of the coil in figure 18. The six equal-length distributor tubes connect to the 2nd, 5th, 8th, 11th, 14th and 17th tubes from the bottom in the 5th row from the right. As for all units the special test expansion valve used in place of the valve furnished with the unit was located remote from the coil. Figure 19 shows schematically the arrangement of this unit and related physical data are given in table 1.

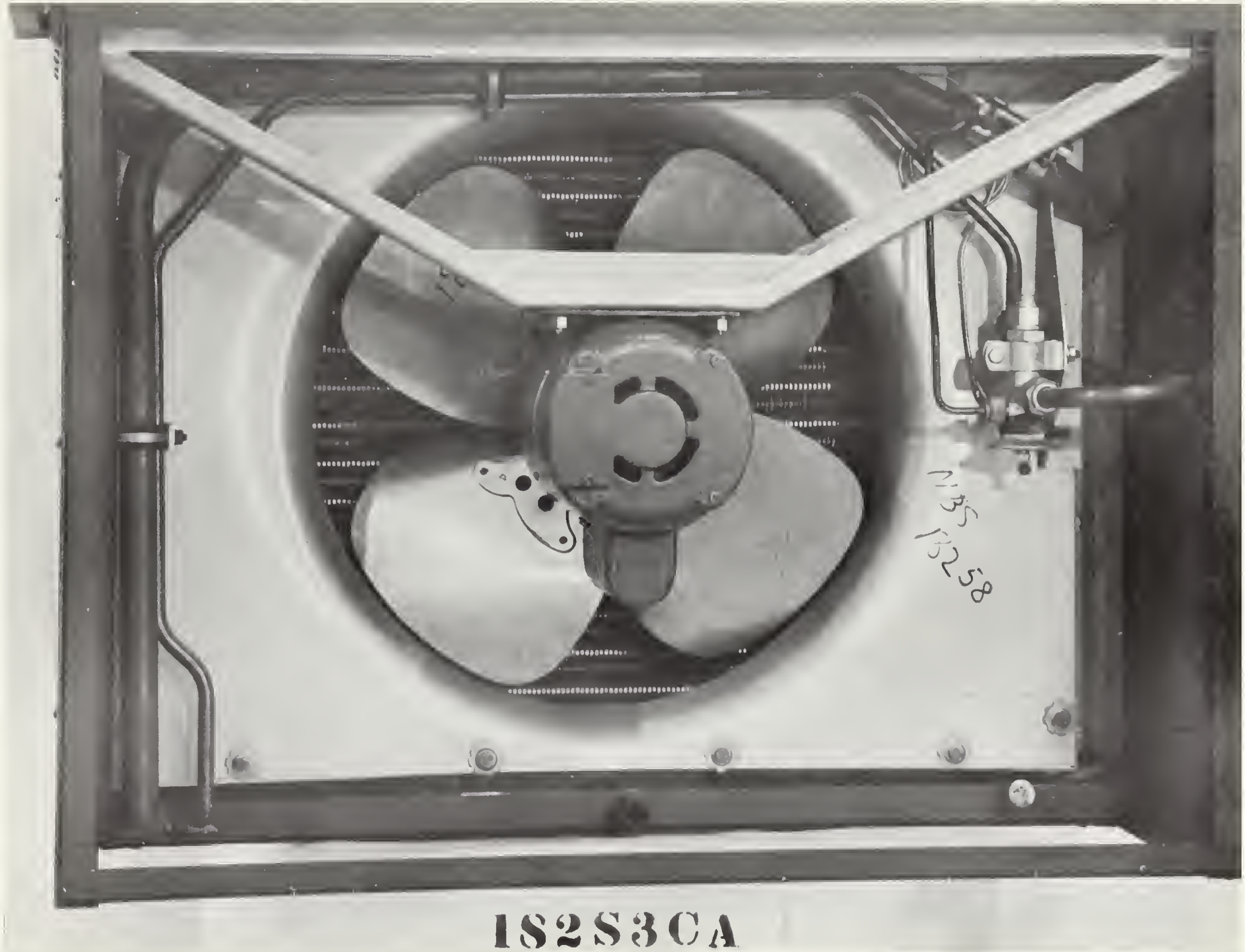


Figure 16. Fully-assembled Size III evaporator (NBS No. 182-58) as supplied.

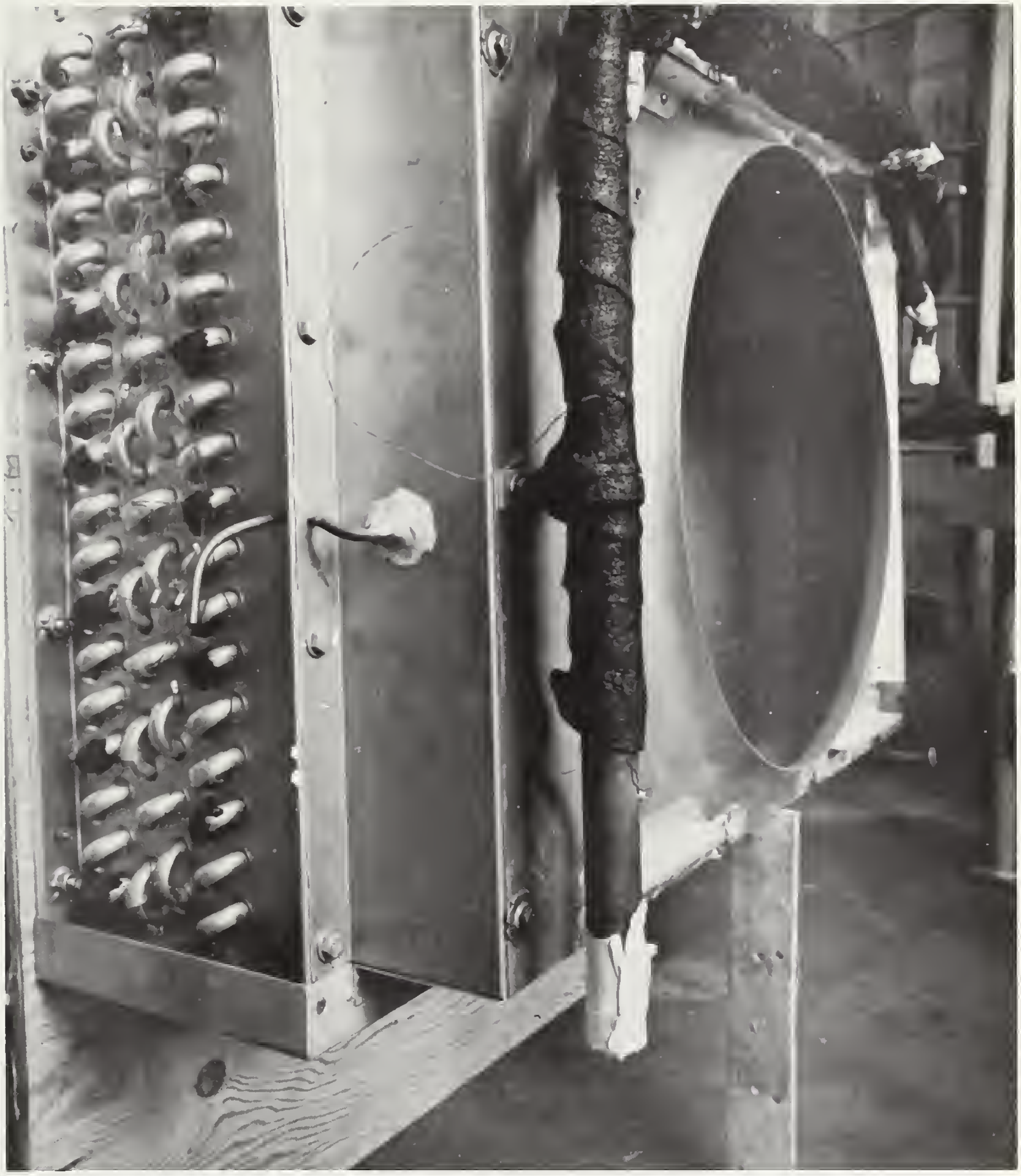


Figure 17. Left end and air discharge side of Size III evaporator (NBS No. 182-58) as mounted for test.

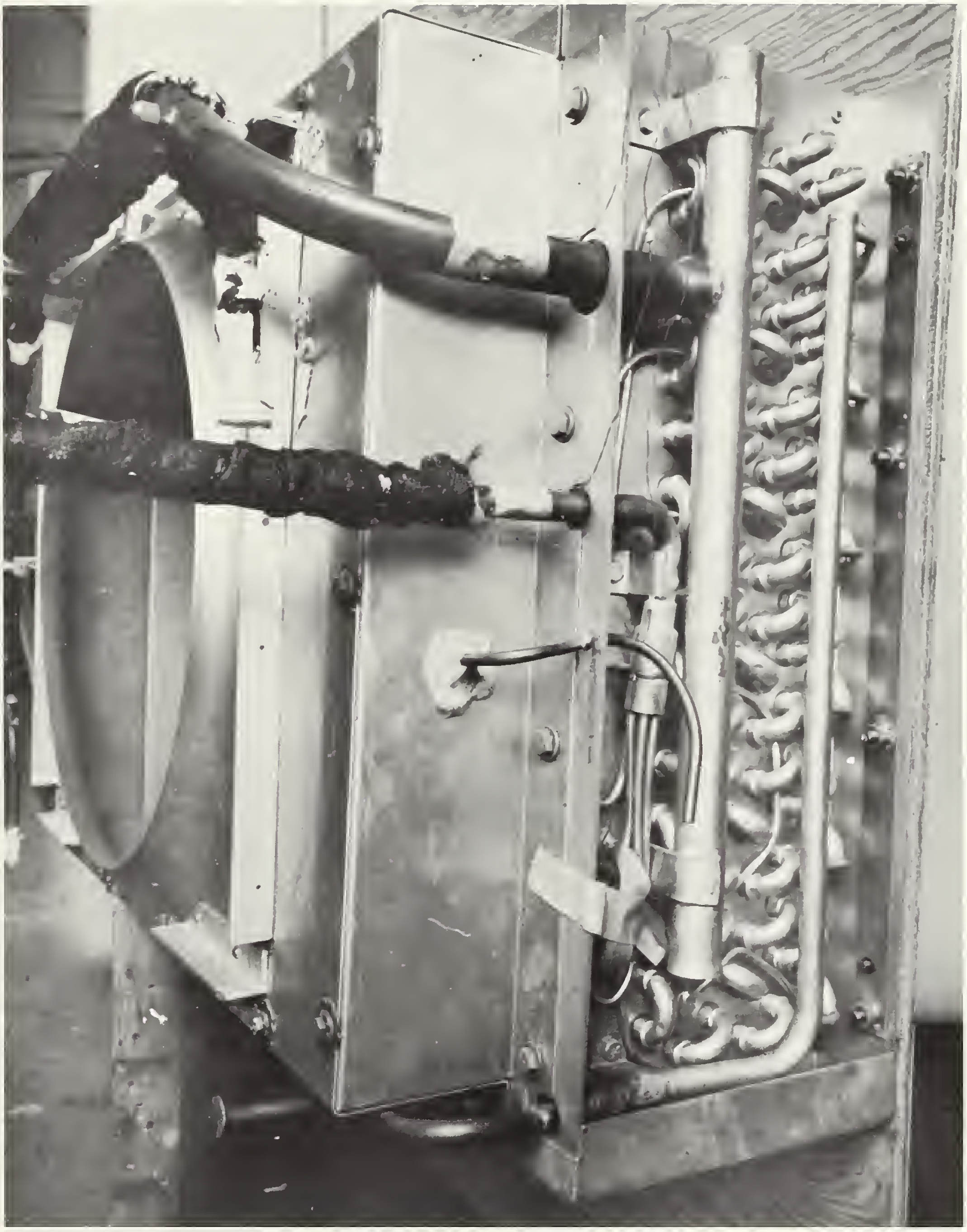


Figure 18. Right end and air discharge side of Size III evaporator (NBS No. 182-58) as mounted for test.

THERMO KING — EVAPORATOR SPECIMEN NBS NO. 182-58 — SIZE III — CLASS A

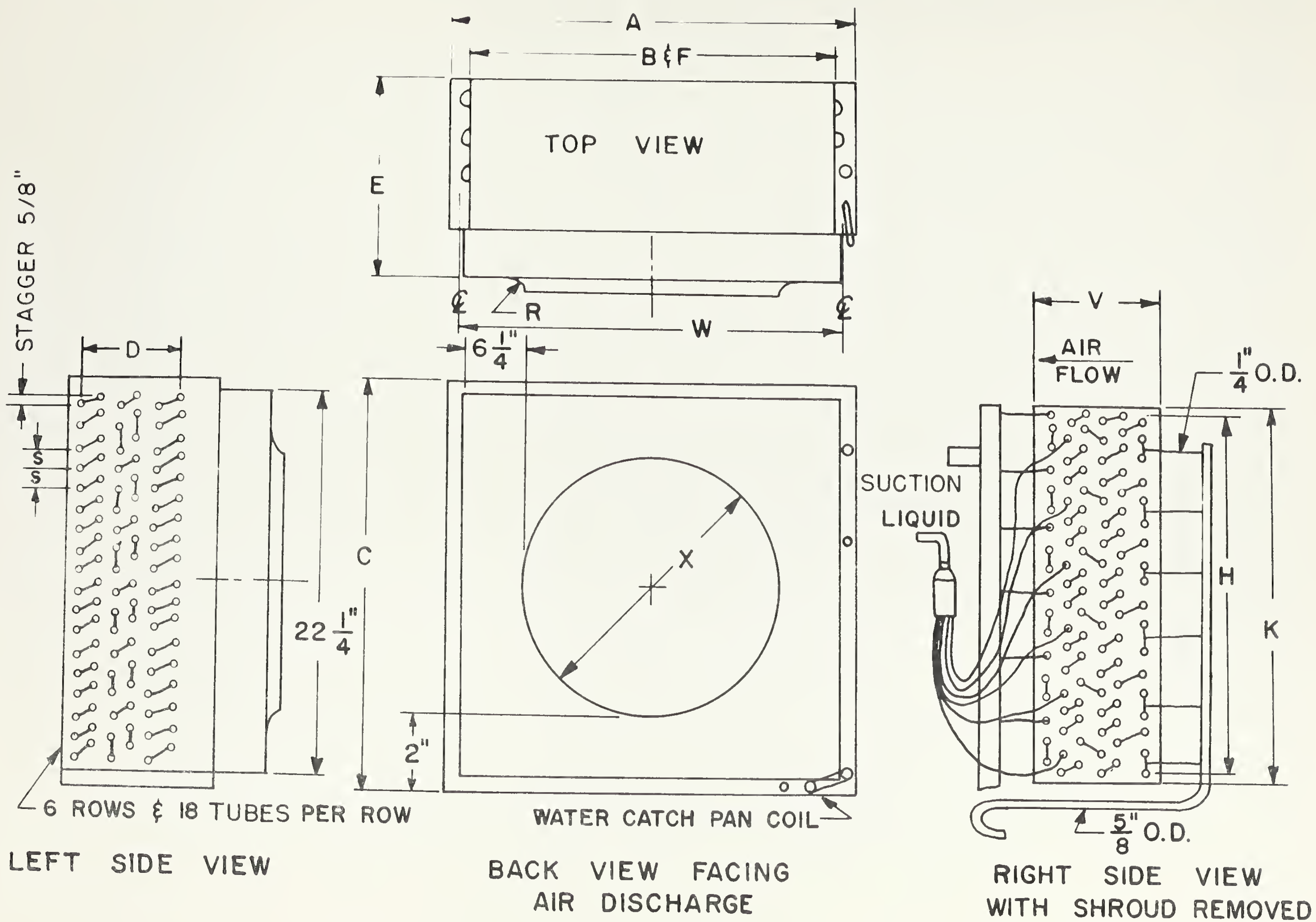


Figure 19

3.1.4 NBS Specimen No. 183-58 was a Size IV Class A evaporator with copper tubes and aluminum fins. Figure 20 shows the orifice and fan side of this unit as supplied. As with the other units, the orifice plate was reversed and the fan replaced to provide draw-through air flow during the tests. Figures 21 and 22, respectively, show the left and right ends of this unit as mounted for test and both show the air discharge side (as tested) with the orifice plate reversed. The integral heat exchanger (insulated for test) formed by soldering the liquid and suction lines together is above and to the left of the fan orifice. In figure 22, the distributor tubes feeding each of the eight circuits are clearly shown. The defrost header, on the right, has connections to the mid-point of these eight circuits. As for all the Thermo King units each coil circuit tube configuration was rectangular and arranged one above the other along the vertical height of the coil. Similar to the Size III this unit was tested as shown in figure 22 with the exterior housing removed, but with the fan and fan motor in place. The discharge duct containing the air mixers was attached to the angle strips on the orifice plate. Figures 23 and 24 are schematic drawings of the Size IV unit and table 1 gives the related physical data.

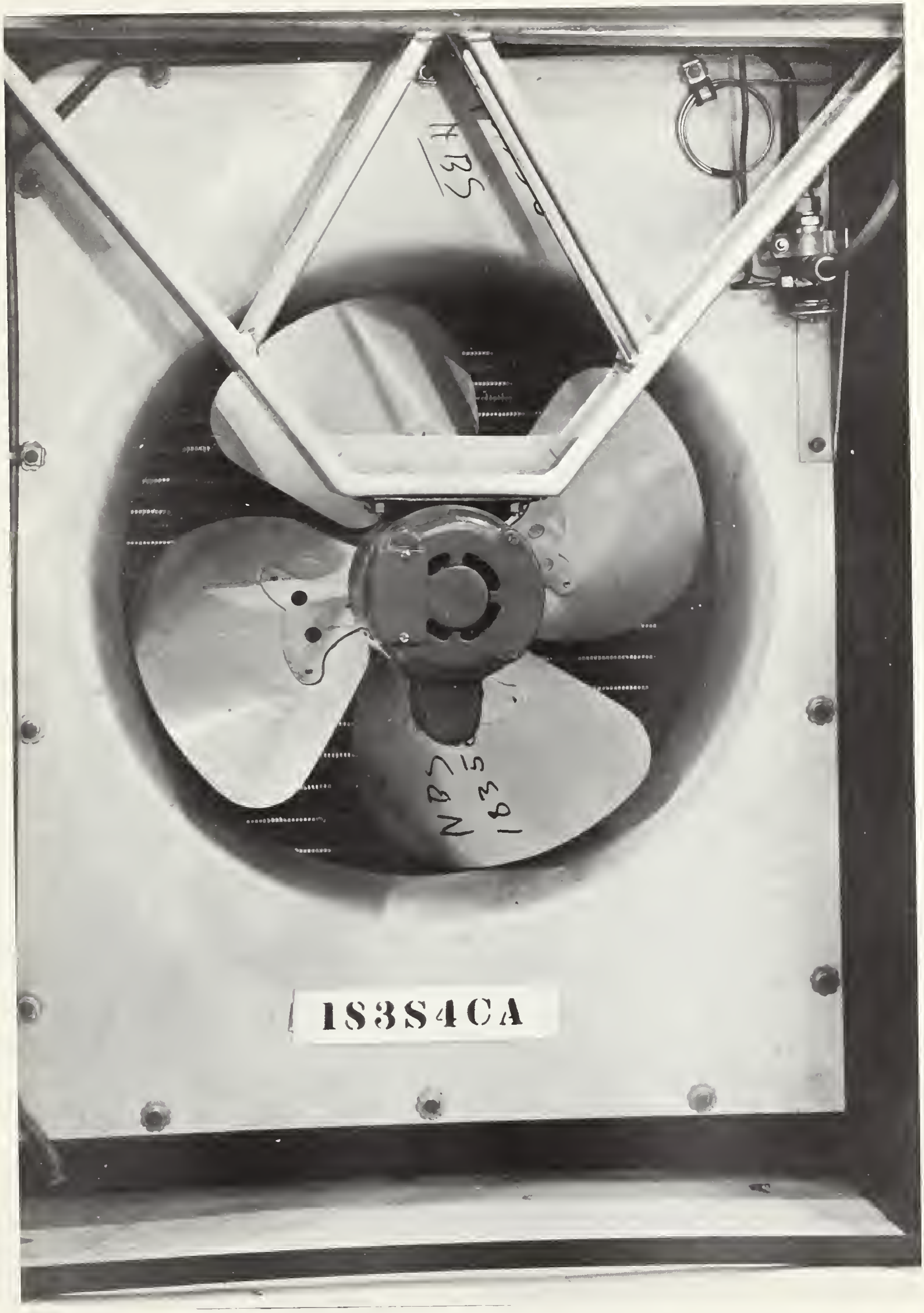


Figure 20. Orifice and fan of the fully-assembled
Size IV evaporator (NBS No. 183-58) as supplied.

Figure 21. Left end and air discharge side of the Size IV evaporator (NBS No. 183-58) as mounted for test.

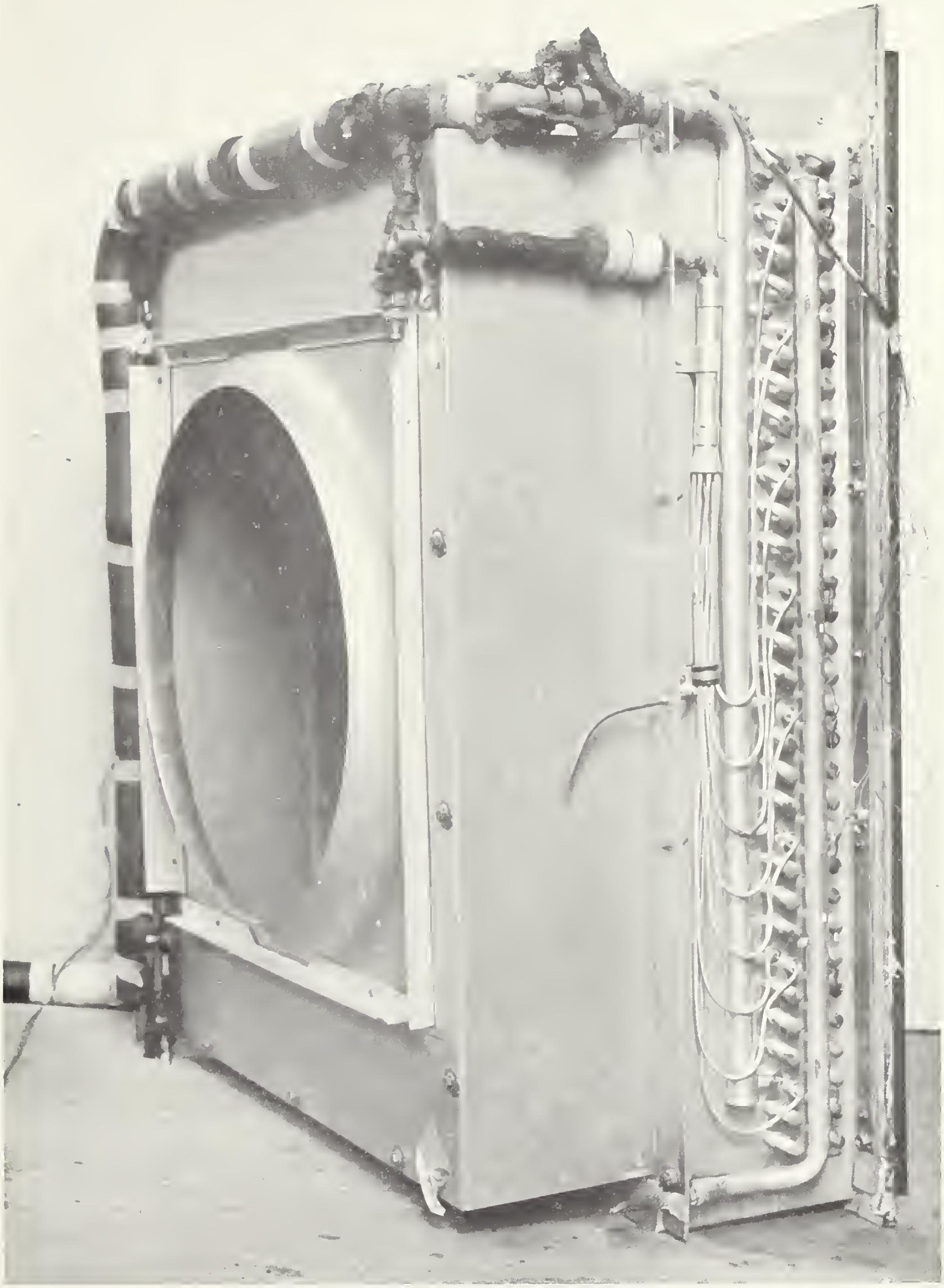


Figure 22. Right end and air discharge side of the Size IV evaporator (NBS No. 183-58) as mounted for test.

EVAPORATOR SPECIMEN

THERMO KING NBS NO. 183-58 SIZE IV CLASS A

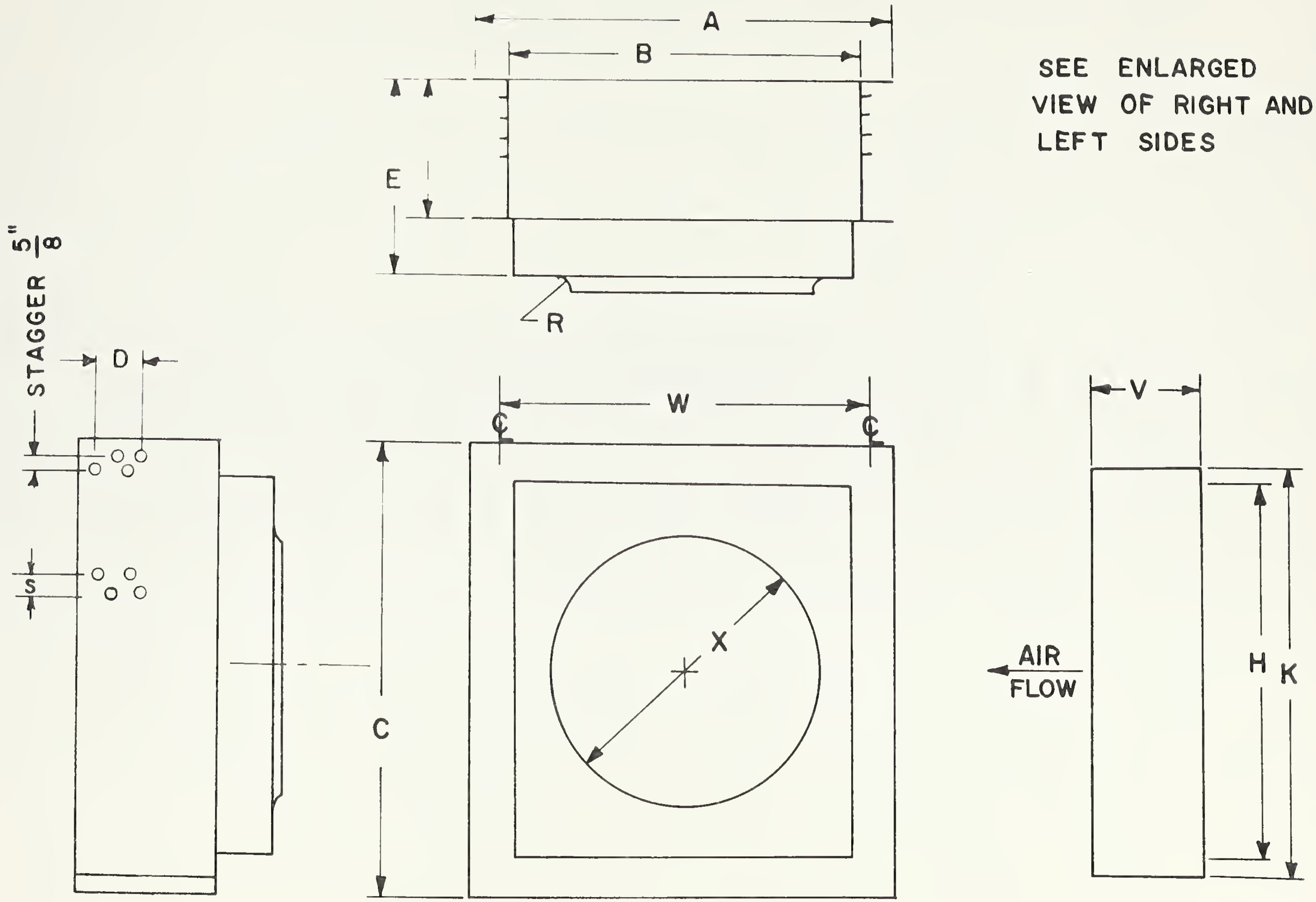


Figure 23

ENLARGED SIDE VIEWS

NBS NO. 183-58

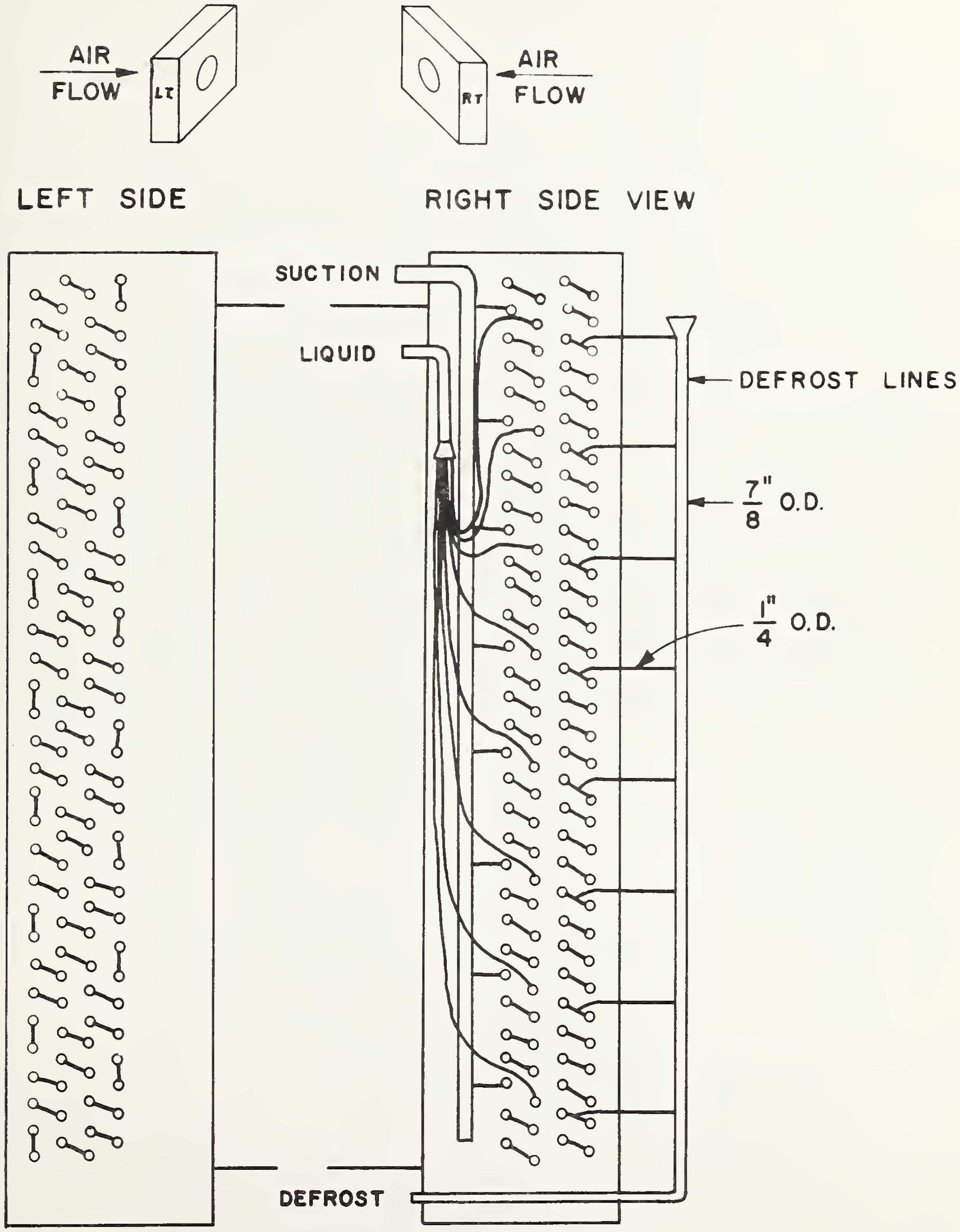


Figure 24

4.0 Data and Results

Each evaporator was studied at four different sets of standard conditions as previously described. Each test required control of refrigerant inlet subcooling and temperature, air inlet temperature and pressure, cubic feet per minute of air flow, and refrigerant outlet pressure and superheat. The variables which fluctuated with capacity were the refrigerant flow rate and the air outlet temperature. Although each evaporator was supplied with its own blow-through fan and fan motor, tests were made using selected draw-through fans identical to those furnished except for the direction of air flow and with an auxiliary blower to adjust the air flow rate to the desired test values. The determination of primary, secondary, and total surface areas were based on the following conditions:

1. Primary area = Number of tubes x length x π x (measured diameter plus twice the fin collar thickness), minus area covered by fins based on fin thickness. Note that fin collars were included as primary area.
2. End sheets and tube area through and beyond end sheets and exposed fin edges were not included.

At the bottom of figure 2 is shown the air mixing duct which was attached to the downstream side of the coil. It was found to be nearly impossible to obtain consistent satisfactory agreement (to within 6 percent) between air and refrigerant side capacity measurements before this mixer was installed in the apparatus ahead of the downstream temperature measurement thermocouples.

Table 2 summarizes the test data and results for the four Thermo King air cooler evaporators.

TABLE 2

CAPACITY TEST DATA

THERMO KING CLASS A AIR COOLER EVAPORATORS

		Nominal Test Conditions			Actual Test Conditions			Superheat, Deg F[b]		Coil Air	Capacity, BTU/H		Results					
Run No.	Size	Air In, °F	Refr., °F[a]	Air Flow, CFM	Air In, °F	Refr., °F[a]	Air Flow, CFM	Evap. Outlet	Air Cooler Outlet[c]	Pressure Drop, In.W.G.	Air Side	Refr. Side	% Diff.[d]	Air Out, °F	Refr. Flow lb./Hour	Fan Power Watts[e]	Capacity Adjusted To QMR&E Conditions, BTU/H[f]
506	I	0	-10	750	0.3	-10.4	740	0.9g	13.2	0.05	2360	2470	4.5	-1.7	46	175	2330
501	I	50,70% RH	35	750	50.2,68%	35.2	760	0.0	7.5	.04	4290	4430	3.2	46.0	81	172	
502	I	30	18	750	30.2	17.6	750	2.8	10.4	.05	2980	3040	1.9	27.3	54	174	
505	I	-10	-22	750	-9.8	-22.8	740	0.9	18.2	.06	2520	2650	4.9	-11.8	50	176	
603	II	0	-10	1100	0.2	-10.4	1100	3.6	16.4	.17	3370	3300	-2.1	-2.2	62	180	3120
601	II	50,70% RH	35	1100	49.8,68%	35.2	1100	4.4	11.9	.12	7600	8000	5.0	44.3	144	178	
602	II	30	18	1100	30.2	17.9	1090	1.8	6.0	.12	4890	4630	-5.6	26.9	86	184	
604	II	-10	-22	1100	-9.8	-23.7	1080	5.1	18.0	.23	4080	4350	6.2	-12.3	80	185	
804	III	0	-10	1500	1.0	-9.9	1500	0.2	11.6	h	8540	8070	-5.8	-3.0	161	304	7430
801	III	50,70% RH	35	1500	50.2,68%	34.7	1500	4.0	12.6	h	12550	12440	-0.9	43.4	227	297	
802	III	30	18	1500	30.7	17.7	1480	-0.3	12.0	h	8540	8070	-5.8	25.6	182	302	
805	III	-10	-22	1500	-9.7	-22.1	1500	-0.5	6.9	h	10850	10600	-2.4	-14.8	216	311	
1207	IV	0	-10	2200	0.5	-10.7	2200	0.9	16.8	.12	9180	9430	2.7	-1.7	183	943	8420
1201	IV	50,70% RH	35	2200	49.7,68%	35.4	2210	0.0	9.0	.09	13030	13220	1.4	45.7	244	852	
1202	IV	30	18	2200	29.4	17.5	2200	0.9	29.4	.08	9360	9350	-0.1	27.0	173	882	
1206	IV	-10	-22	2200	-10.6	-22.7	2150	1.4	-10.6	.14	11780	12170	3.2	-13.6	256	932	

a. Refrigerant temperature corresponding to pressure at suction outlet.

b. ASHRAE Standard 25-56 recommends 5 to 8 deg F superheat at the evaporator outlet.

c. Thermo King air coolers equipped with integral heat exchangers.

d. $\frac{\text{Refr. Side} - \text{Air Side}}{\text{Refr. Side}} \times 100$

e. Air pressure drop across fan adjusted to produce required air flow; power not indicative of free air delivery.

f. Measured capacity adjusted to QMR&E nominal condition = $\frac{0 - (-10)}{\text{T air in} - \text{T refrigerant}} \times$ Measured capacity.

g. Superheat values less than 3 deg F indicate possibility of liquid flooding into heat exchanger.

h. Valid readings not obtained.

5.0 Discussion and Conclusions

The tests covered in this report were part of a series intended to provide a comparison of the cooling capacities of refrigeration evaporators produced by three manufacturers for use in military forced circulation air coolers. This report covers results of tests of evaporators manufactured by Thermo King Corporation, purchased under the QMR&E Interim Purchase Description, IP/DES S-9-8, dated January 31, 1958.

To provide a meaningful comparison of coil performance leading to interchangeability of evaporators under conditions where the air flow rate will be a function of the performance of a suitably-selected military standard fan, all coils in this series were tested at the minimum air flow rate specified in IP/DES 2-9-8, even though the fans supplied with each evaporator would deliver a different air flow rate under the normal free air delivery conditions. It is likely that the cooling capacities obtained with the minimum air flow rate were less than the capacities which would be obtained if the free air delivery rate were greater than the minimum. As described earlier the minimum air flow rate was obtained by varying the air pressure downstream of the fan.

To remove from the tests the variability of different thermal expansion valves, a specially-selected valve was used to test all coils of the same size. In addition these special test valves were set to maintain essentially steady-state refrigerant flow conditions as opposed to the hunting characteristic of normal thermal expansion valves. It is to be expected that higher cooling capacities are obtained with steady-state operation, other conditions being equal. This was confirmed by a preliminary test of one of the coils in this series.

Use of integral liquid-suction heat exchangers can be a factor where interchangeability is concerned. The Thermo King coils covered in this report were equipped with heat exchangers, as were the coils supplied by one other manufacturer in this series. The coils from the third manufacturer were not so equipped. This should be considered in preparation of the military standard for such units. As discussed under Test Procedures the refrigerant superheat requirement of 5 to 8 deg F specified in ASHRAE Standard 25, the capacity test method prescribed in IP/DES S-9-8, had to be modified for use with the evaporators equipped with integral heat exchangers. It should be noted that ASHRAE Standard 25 describes test methods for fully assembled air coolers whereas the principal interest in these tests was directed to the evaporators in such units.

As shown in Table 2 capacity tests of each coil were made at several conditions in addition to the IP/DES S-9-8 required conditions of -10 ^{o}F refrigerant and 0 ^{o}F entering air. The performance of the four Thermo King evaporators in relation to the QMR&E required capacities was as follows:

Size	Capacity, Btuh Measured	Capacity, Btuh Required	Percent of required capacity
I	2330	4500	52
II	3120	6500	48
III	7430	10000	74
IV	8420	13000	65

The average measured capacities, in Btuh, for the three makes of coils tested, at the QMR&E conditions, were; Size I 3030, Size II 4010, Size III 7620, and Size IV 9710.

Two coefficients related to coil capacity which outline relative performance are

(1) $\dfrac{\text{Btuh}}{(\text{Face area, ft}^2)\ (\text{deg F})}$ and (2) $\dfrac{\text{Btuh}}{(\text{Total surface area, ft}^2)\ (\text{deg F})}$

For the QMR&E conditions the comparisons of the Thermo King coils with the other makes tested were:

	Btuh / (Face area, ft^2) (deg F)		Btuh / (Total surface area, ft^2) (deg F)	
Size	Thermo King	Range of three makes	Thermo King	Range of three makes
I	76	76 - 165	19	19 - 38
II	106	106 - 190	18	18 - 32
III	157	157 - 161	29	28 - 38
IV	97	97 - 139	26	26 - 38

One factor which may have had a significant influence on the observed variability of coil performance as indicated by these coefficients was the distribution of refrigerant in proper amounts to the several parallel circuits. In particular the method of connecting the defrost headers should be examined for possible interference with proper distribution.

In view of the fact that the units tested were of a prototype nature they were not examined in rigorous detail for dimensional or material compliance with the purchase description. Table 1 lists the physical data for each unit.

As supplied for test each of the four Thermo King evaporators, contrary to the requirement as shown in sketch 5 of the purchase description, was equipped with a blow-through fan, as were each of the evaporators supplied by the other two manufacturers. The fans were corrected for test purposes as described under Test Procedure.

The change in ASHRAE Standard 25 substituting the use of a second simultaneous independent measurement of the refrigerant-side capacity for the previous psychrometric apparatus air-side measurement emphasizes the importance of valid calibration of the integrating liquid refrigerant flow meters. Experience gained in this series

of tests showed that calibration of these devices using the same fluids as those to be measured is necessary for all instruments affected by pressure, lubricity or viscosity. Air-side measurements were retained in this series inasmuch as the psychrometric apparatus had been constructed prior to the change in ASHRAE Standard 25. Experience gained in this series of tests indicated the necessity for adequate mixing of the air, particularly that leaving the coil (or fan), if the temperature at that point is to be used to obtain a heat balance.

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